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Abstract. Recognition of sound sources and events is an important process in sound perception and has been studied in many research domains. Conversely sounds that cannot be recognized are not often studied except by electroacoustic music composers. Besides, considerations on recognition of sources might help to address the problem of stimulus selection and categorization of sounds in the context of perception research. This paper introduces what we call abstract sounds with the existing musical background and shows their relevance for different applications.

Key words: abstract sound, stimuli selection, acousmatic

1 Introduction

How do sounds convey meaning? How to identify acoustic characteristics that convey the relevant information in sounds? These questions interest researchers within various research fields such as cognitive neuroscience, musicology, sound synthesis, sonification, *etc.* Recognition of sound sources, identification, discrimination and sonification deal with the problem of linking signal properties and perceived information. In several domains (linguistic, music analysis), this problem is known as "semiotics" [1]. The analysis by synthesis approach [2] has permitted to understand some important features that characterize the sound of vibrating objects or interaction between objects. A similar approach was also adopted in [3] where the authors use vocal imitations in order to study human sound source identification with the assumption that vocal imitations are simplifications of original sounds that still contain relevant information.
Recently, there has been an important development in the use of sounds to convey information to a user (of a computer, a car, *etc.*) within a new research community called auditory display [4] which deals with topics related to sound design, sonification and augmented reality. In such cases, it is important to use

sounds that are meaningful independently of cultural references taking into account that sounds are presented through speakers concurrently with other audio/visual information.
As a function of research topics, authors focused on different sound categories (*i.e.* speech, environmental sounds, music or calibrated synthesized stimuli). In [5], the author proposed a classification of everyday sounds according to physical interactions from which the sound originates. Such classification contains any sounds except synthesized sounds that do not imitate everyday sounds. When working within synthesis and/or sonification domains, the aim is often to reproduce the acoustic properties responsible for the attribution of meaning and thus, sound categories can be considered from the point of view of semiotics *i.e.* focusing on what information can be gathered in sounds. In this way, we considered a specific category of sounds that we call "abstract sounds".
This category includes all the sounds that cannot be associated with an identifiable source. It includes environmental sounds that cannot be easily identified by listeners or that give rise to many different interpretations depending on listeners and contexts. This also includes synthesized sounds, and laboratory generated sounds if they are not associated with a clear origin. For instance, alarm or warning sounds cannot be considered as abstract sounds. In practice, recordings with a microphone close to the sound source and some synthesis methods like granular synthesis are especially efficient for creating abstract sounds. Note that in this paper, we mainly consider acoustically complex stimuli since they best meet our needs in the different applications (as discussed further).

Various labels that refer to abstract sounds can be found in the literature: "confused" sounds [6], "strange" sounds [7], "sounds without meaning" [8]. Conversely, [9] uses the term "source-bonded" and the expression "source bonding" for the "The natural tendency to relate sounds to supposed sources and causes". Chion introduced "acousmatic sounds" [10] in the context of cinema and audiovisual applications with the following definition: "sound one hears without seeing their originating cause - an invisible sound source" (for more details see section 2).
The most common expression is "abstract sounds" [11–13] particularly within the domain of auditory display, when concerning "earcons" [14]. "Abstract" used as an adjective means "based on general ideas and not on any particular real person, thing or situation" and also "existing in thought or as an idea but not having a physical reality"[1]. For sounds, we can consider another definition used for art "not representing people or things in a realistic way"[1]. Abstract as a noun is "a short piece of writing containing the main ideas in a document"[1] and thus share the ideas of essential attributes which is suitable in the context of semiotics. In [16], the author discussed the different uses and meanings of the word "concrete", and report that "concrete" has acquired a particular meaning in English regarding the use of recognizable sounds sources". In [17], authors wrote: "Edworthy and Hellier (2006) suggested that abstract sounds can be in-

[1] Definitions from [15]

terpreted very differently depending on the many possible meanings that can be linked to them, and in large depending on the surrounding environment and the listener."

In fact, there is a general agreement for the use of the adjective "abstract" applied to sound that expressed both the ideas of source recognition and different possible interpretations.

This paper will first present the existing framework from electroacoustic music composers and researchers for the use of abstract sounds. We will then discuss some important aspects that should be considered when conducting listening test with a special emphasis on the specificities of abstract sounds. Finally, three practical uses of abstract sounds in different domains will be presented.

2 The acousmatic approach

Even if the terms "abstract sounds" was not used in the context of electroacoustic music, it seems that this community was one of the first to consider the question of recognition of sound sources and to use such sounds. In 1966, P. Schaeffer who was both a musician and a researcher published the *Traité des objets musicaux* [18], which contains more than ten years of research on electroacoustic music. With a multidisciplinary approach, he intended to carry out fundamental music research that include both "Concrète"[2] and traditional music. One of the first concepts he introduced was the so called "acousmatic" listening, related to the experience of listening to a sound without paying attention to the source or the event. The word "acousmatic" is at the origin of many discussions, and is now mainly employed in order to describe a musical trend. Discussions about "acousmatic" listening was kept alive due to a fundamental problem in concrete music. Indeed, for music composers the problem is to create new meaning from sounds that already carry information about their origins. In compositions where sounds are organized according to their intrinsic properties, thanks to the acousmatic approach, information on the origins of sounds is still present and interacts with composers' goals.

There was an important divergence of points of view between Concrete and Elektronische music (see [19] for a complete review), since the Elektronische music composers used only electronically generated sounds and thus avoided the problem of meaning [20]. Both Concrete and Elektronische music have developed a research tradition on acoustics and perception but unfortunately only Schaeffer adopted a scientific point of view. In [16], the author wrote: "Schaeffers decision to use recorded sounds was based on his realization that such sounds were often rich in harmonic and dynamic behaviors and thus had the most potential for his project of musical research". This work is of importance for electroacoustic musicians but almost unknown by auditory perception researchers since there is

[2] The term "concrete" is related to composition method which is based on concrete material *i.e* recorded or synthesized sound, in opposition with "abstract" music which is composed in an abstract manner i.e from ideas written on score, and become "concrete" afterwards.

no published translation except for concomitant works [21] and Chion's *Guide des objets musicaux* [3]. As reported in [22], translating Schaeffer's writing is extremely difficult since he used neologisms and very specific meanings of certain words. However, recently, there was a growing interest in this book and in particular in the domain of music information retrieval, for the morphological sound description [11, 13, 23]. Authors indicated that in the case of what they call "abstract" sounds, classical approaches based on sound source recognition are not relevant and thus base their algorithms on Schaeffer's morphology an typology classifications.
Morphology and typology have been introduced as analysis and creation tools for composers as an attempt to construct a music notation that includes electroacoustic music and therefore any sound. Typology classification (cf. figure 1) is defined by a combination of spectral (mass) and dynamical (*facture*[4]) "profiles" with considerations of how complex they are. There are nine central categories of "balanced" sounds where "balanced" means that the variations are neither too rapid and random nor too slow or nonexistent. Those nine categories are combinations of three *facture* profiles (sustained, impulsed or iterative) and three mass profiles (tonic, complex and varying). On both sides of the "balanced objects" there are additional categories for which mass and *facture* profiles are too simple/repetitive or vary too much. In all, the typology classification consists of twenty-eight categories.
Note that some automatic classification methods are available [13]. In [24] the authors proposed an extension of Schaeffer's typology that includes graphical notations.

Since the 1950s, electroacoustic music composers have addressed the problem of meaning of sounds and provided an interesting tool for classification of sounds with no *a priori* differentiation on the type of sound. For sound perception research, those categories may be useful since they are suitable for all sounds. The next section will detail the use of such classification for the design of listening tests.

3 Design of listening tests using abstract sounds

Listening tests are at the basis of many studies in sound perception. The design of listening tests implies considerations of different aspects of perception that interact with intended measurement. For instance, it is important to design calibrated stimuli and experimental procedures to best control the subjects' evaluations. We propose to discuss such aspects in the context of abstract sounds.

[3] Translation by J.Dack available at `http://www.ears.dmu.ac.uk/spip.php?page=articleEars&id_article=3597`

[4] As discussed in [22] even if *facture* is not a common English word, there is no better translation from French

		Facture						
		Unpredicable evolution	Non existent evolution	formed Sustained	Impulse	formed Iterative	Non existent evolution	Unpredicable evolution
Mass	Tonic (definite pitch)	En	Hn	N	N'	N''	Zn	An
	Complex	Ex	Hx	X	X'	X''	Zx	Ax
	Varying	Ey	Tx/Tn	Y	Y'	Y''	Zy	Ay
	Unpredicable	E	T	W	phi	K	P	A

Fig. 1. Schaeffer's typology. Note that some columns are redundant since the tab must be read from center to borders. For instance, "No evolution" in the right part of the tab correspond to endless iterations whereas "No evolution" in the left part correspond to sustained sound (with no amplitude variations).
Translation from [22]

3.1 Stimuli

It is common to assume that perception differs as a function of sound categories (*i.e.* speech, environmental sounds, music). Even more, these categories are underlying elements defining a research area. Consequently, it is difficult to determine a general property of human perception by collecting results obtained from different studies. For instance, results from loudness studies based on elementary synthesized stimuli (sinusoids, noise, *etc.*) cannot be directly adapted to complex environmental sounds as reported by [25]. Furthermore, the judgment of listeners could differ for sounds belonging to a same category. For instance, in the environmental sound category, [12] have shown specific categorization strategies for sounds that involve human activity.
When there is no hypothesis regarding the signal properties, it is important to gather sounds that present a large variety of acoustic characteristics as discussed in [26]. Schaeffer's typology offers an objective selection tool than can help the experimenter to construct a very general sound corpus representative of most existing sounds. Besides, abstract sounds may constitute a good compromise in terms of acoustic properties between elementary (sinusoids, noise, etc.) and ecological (speech, environmental and music) stimuli. Furthermore, abstract sounds cover all the typology categories by contrast with environmental sounds for example that do not concern certain rows of the classification table (mainly the "balanced" objects).

A corpus of abstract sounds can be constituted in different ways. Many databases available for audiovisual applications contain such sounds (see [26]). Different synthesis techniques (like granular or FM synthesis, *etc.*) are also efficient to create abstract sounds. In [8] and further works [27, 28], the authors presented some techniques to transform any recognizable sound into an abstract sound, preserving several signal characteristics. Conversely, many transformations drastically alter the original environmental or vocal sounds by modifying some important acoustic attributes. For instance, [29] has shown that high and low-pass filtering influence the perceived naturalness of speech and music sounds. Since abstract sounds do not convey precise meaning, it is possible to use them in different ways according to the needs of the experience. For instance, a same sound corpus can be evaluated in different contexts in order to study specific aspects of the information conveyed by the sounds. In particular, we will see how the same set of abstract sounds was used in 2 different studies described in sections 4.3 and 4.1.

3.2 Procedure

In the case of abstract sounds, it is important to verify that they are actually "abstract" for most listeners. In a musical context, D. Smalley [30] has introduced the expression "surrogacy" level (or degree) to quantify the ease of source recognition. This level is generally evaluated by using identification tasks. In [6], the authors describe three methods: 1) Free identification tasks that consists of associating words or any description with sounds [31]. 2) Context-based ratings, which are comparisons between sounds and other stimuli. 3) Attribute rating, which is a generalization of the semantic differential method. The third method may be the most relevant since it provides graduated responses on an unlimited number of scales. In particular, we will see in section 4 that we evaluated the degree of recognition of abstract sounds ("the sound is easily recognizable or not") by asking listeners to use a non graduated scale from "not recognizable" to "easily recognizable".

There are many evidences for interaction between auditory and visual information (see [32] for a review). By definition, abstract sounds are not easily associated with a source (and to the corresponding label). Nevertheless, they can be attributed to several meanings that may depend on the type of experimental procedure and task. In particular, we will see that it is possible to take advantage of this variability to highlight for example differences between groups of listeners as described in section 4.1.

3.3 Type of listening

In general, perception research distinguishes analytic and synthetic listening. Given a listening procedure, subjects may focus on different aspects of sounds since different concentration and attention levels are involved. From a different point of view, [33] introduced the terms "everyday listening" (as opposed to "musical listening") and argued that even in the case of laboratory experiences, listeners are naturally more interested in sound source properties than in intrinsic properties and therefore use "everyday listening". [18] also introduced different

types of listening ("hearing", "listening", "comprehending", "understanding") and asserted that when listening to a sound we switch from one type of listening to another. Even if different points of view are used to define the different types of listening, they share the notions of attention direction and intention when perceiving.
Abstract sounds might help listeners to focus on intrinsic properties of sound and thus to adopt musical listening.
An other aspect that could influence the type of listening and therefore introduce variability in responses is the coexistence of several streams in a sound[5]. If a sound is composed of several streams, listeners might focus on different elements without possible control from the experimenter. Since abstract sounds have no precise meaning to be preserved, it is possible to proceed to transformations that select one stream (and alter the original meaning). This is not the case for environmental sound recordings for instance, since transformations can make them unrecognizable. Note that classification of sounds with several streams according to Schaeffer's typology might be difficult since they present concomitant profiles associated with distinct categories.

4 Potentials of abstract sounds

As described in section 2, potentials of abstract sounds was initially shown in a musical context. In particular, their ability to evoke various emotions was fully investigated by electroacoustic composers. In this section, we present some applications in which we used abstract sounds in three different research domains, *i.e.* sound synthesis, cognitive neuroscience and clinical diagnosis. Note that we only aim at giving an overview of some experiments that use abstract sounds, in order to discuss the reasons that motivated their use. Details of the material and methods can be found in the articles referred in the following sections.

Stimuli used in the experiments The three experiments partially shared the same stimuli. We collected abstract sounds provided by electroacoustic composers. Composers constitute an original resource of interesting sounds since they have thousands of specially recorded or synthesized sounds, organized and indexed to be included in their compositions. From these databases, we selected a set of 200 sounds[6] that was representative of the typology proposed by Schaeffer (cf. tab 1). A subset of sounds was then selected according to the needs of each experiment:
In [36] (section 4.1), we chose 20 sounds from the previous set of 200 sounds by a pre-test on seven subjects and selected sounds that best spread in the space of measured variables (the perceptual dimensions). This procedure is similar to

[5] Auditory streams have been introduced by Bregman [34], and describe our ability to group/separate different elements of a sound

[6] Some examples from [35] are available at `http://www.sensons.cnrs-mrs.fr/CMMR07_semiotique/`

experiment design methods, for protocols where stimuli are synthesized. This preselection was validated by a second pre-test on fourteen subjects that produced similar repartition of the sounds along the perceptual dimensions.
In [37] (section 4.2), only sounds from the nine "balanced" (see section 2) categories were used. Abstract sounds were presented successively to listeners who were asked to write the first words that came to their mind after listening. A large variety of words were given by listeners, for instance a sound obtained the following responses: "dry, wildness, peak, winter, icy, polar, cold". Nevertheless, for most sounds, it was possible to find a word that was accepted as coherent by more than 50% of the listeners. This step allowed us to validate the abstract sounds since no label referring to the actual source was given.
In [35, 38] (section 4.3), we selected 40 sounds among the 200 using the procedure described above (pre-test and optimization of the repartition of sounds). We then conducted an evaluation test of the 40 sounds on 29 listeners through 2 questions rated on linear scales:

- "Is the sound source recognizable?" (rated on a non graduated scale from "not recognizable" to "easily recognizable")
- "Is the sound natural?" (rated from "natural" to "synthetic")

When the sources were judged "recognizable", listeners were asked to write a few words to describe the source.
We found a correspondence between responses of the two questions: the source is perceived natural as long as it is easily recognized (R=.89). Note that abstract sounds were judged as "synthesized" sounds even if they actually were recordings from vibrating bodies.
Obviously, for each experiment, loudness of sounds was equalized and the sounds' onset and offset were smoothed to avoid clicks.

4.1 Bizarre and familiar sounds

Abstract sounds are not often heard in our everyday life and could even be completely novel for listeners. Thus abstract sounds might be considered as "strange" or "bizarre". As mentioned above, the judgements of abstract sounds are highly subjective for listeners. In some cases, it is possible to use this subjectivity to investigate some specificities of human perception and in particular, to highlight differences of sound evaluation between groups of listeners. From those considerations, [36] has explored the perception of bizarre and familiar sounds in patients with schizophrenia. Indeed, the concept of "bizarre" is one important element from standard classification of mental disorders (DSM - IV) for schizophrenia [39] pp. 275. An other frequently reported element is the existence of auditory hallucinations[7], *i.e.* perception without stimulation.
The study employed both environmental and abstract sounds to explore individual differences in the judgement of sounds. The procedure was equivalent to

[7] "[...] auditory hallucinations are by far the most common and characteristic of Schizophrenia." [39] pp. 275

semantic differential protocol, which consisted in rating sounds on continuous scales defined by an adjective (by contrast, classical differential semantic uses an adjective and an antonym to define each scale). Sounds were evaluated on six dimensions along linear scales: "familiar", "reassuring", "pleasant", "bizarre", "frightening", "invasive"[8]. Preliminary results showed that there was a significant difference between patients with schizophrenia and control groups along the familiar/bizarre dimensions: abstract sounds were judged more familiar by patients than by control subjects. Further analysis and testing (for instance brain imaging techniques) will be conducted in order to better understand these differences and in particular, the tendency of patients with schizophrenia to hyper-familiarize the abstract sounds.

4.2 Reduction of linguistic mediation and access to different meanings

Within the domain of cognitive neuroscience, a major issue is to determine whether similar neural networks are involved in the allocation of meaning for language and other sounds. A well-known protocol largely used to investigate semantic processing in language, *i.e.* the semantic priming paradigm [40], has been applied to other stimuli such as pictures, odors and sounds. One difficulty that occurs when considering non-linguistic stimuli, is the potential effect of linguistic mediation. For instance watching a picture of a bird or listening to the song of a bird might automatically activate the verbal label "bird"). In this case, the conceptual priming cannot be considered as purely non-linguistic because of the implicit naming induced by the stimulus processing. Abstract sounds are interesting candidates to weaken this problem, since they are not easily associated with a source and therefore may reduce the automatic and immediate verbal labelling.

However, when listeners are asked to label abstract sounds, we assume that multiple evocations are enabled. In other words, a given abstract sound can be associated with different labels by listeners depending on the task and the context. In [37], the goals were to determine how a sense is attributed to a sound and whether there are similarities between sound and word brain processing. For that, a priming protocol was used with word/sound pairs and the degree of congruence between the prime and the target was manipulated. In a first experiment a written word (prime) was visually presented before a sound (target) and subjects had to decide whether or not the sound and the word fit together. In a second experiment, presentation order was reversed (*i.e.* sound presented before word). Results showed that participants were able to evaluate the semiotic relation between the prime and the target in both sound-word and word-sound presentations with relatively low inter-subject variability and good consistency (see [37] for details on experimental data and related analysis). This

[8] These are arguable translations from French adjectives: familier, rassurant, plaisant, bizarre, angoissant, envahissant

result indicated that abstract sounds are suitable for studying conceptual processing. Moreover, their contextualization by the presentation of a word reduced the variability of interpretations and led to a consensus between listeners. The study also revealed similar electrophysiological patterns on both abstract sounds and word targets, supporting the assumption that similar processing is involved for sounds and words.

4.3 Sound synthesis

Intuitive control of synthesizers through high-level parameters is still an open problem in virtual reality and sound design. Both in industrial and musical contexts, the challenge consists of creating sounds from a semantic description of their perceptual correlates. For this purpose, we proposed a general methodology based on evaluation and analysis of abstract sounds. Indeed, as discussed formerly, abstract sounds can be rich from an acoustic point of view and allow testing different spectro-temporal characteristics at the same time. Thus they might help to identify general signal properties that might be valid for different categories of sounds. They are particularly designed for restitution through speakers (as this is the case for synthesizers).

Given a set of desired control parameters and a set of sounds, the proposed method consists of asking listeners to evaluate the sounds on scales defined by control parameters. Sounds with same/different values on a scale are then analyzed in order to identify signal correlates. Finally, using feature based synthesis [41], signal transformations are defined which may correspond to targeted control parameters.

In [35], we addressed the control of perceived movement evoked by monophonic sounds. Note that in the case of movement, we are aware that the recognition of the physical sound source can introduce a bias in the evaluation. If the source can be easily identified, the corresponding movement is more likely to be established: a car sound only evokes horizontal movement and cannot fall or go up. We conducted a free categorization task asking subjects to group sounds that evoke a similar movement and to label each category. This method aims at identifying sound categories and represents therefore a first step towards the identification of perceptually relevant sound parameters. Based on subjects' responses, we identified six main categories of perceived movements: "rotate", "fall down", "approach", "pass by", "go away"and "go up"and determined a set of sounds representative of each category.

This study is still in progress and continues in [38], where we improve the perceptual characterization of movements through a new methodology. Movements are evaluated with a drawing interface that allows non-exclusive categorization (sounds can rotate and go-up at the same time) and where drawing parameters will correspond to control parameters of the synthesizer. Preliminary results showed that it is possible to determine the relevant control parameters and the needed precision. Abstract sounds allowed us to test a wide variety of acoustic characteristic that may be responsible of the perception of movement.

5 Conclusion

In this paper, we have discussed the problem of sound stimulus selection and interaction between information they convey and information that actually is of interest in an experiment. A review of studies that used abstract sounds has clarified the underlying notions. Abstract sounds can be considered as "unrecognizable", "synthetic" and "bizarre" depending on context and task.

We also discussed that several meanings can be attributed to a same abstract sound and might be used either to orient the type of listening adopted by listeners or to study individual differences. Several arguments in favor of the use of abstract sounds are still to be validated. In particular the reduction of interaction between source recognition and dimension measured in a listening test should be addressed in further research.

The richness of signal characteristics of abstract sounds and the thoughts on recognition of sound sources might open some perspectives in sound perception studies. For instance abstract sounds might help in proposing a general categorization of sounds for research purpose. Indeed, it is known that categorization is supposed to help reducing the complexity of a problem. In auditory perception research there are implicit categories of sounds that distinguish different domains (verbal/non verbal sounds, environmental sounds, music). Therefore, it is possible to propose a categorization based on information available in sounds with a particular emphasis on the context of use. For instance, it might be interesting to consider different levels of accordance between listeners, in tasks where they are told to label sounds. Such levels might help to define continuous distinctions of verbal and non-verbal sounds.

Another perspective is the constitution of a database regrouping both results from different perceptual studies and signal analysis. Such database might facilitate the setting up of listening tests and increase efficiency of research as proposed in the case of music application [42].

Abstract sounds are used in musical context, in cinema and in other audiovisual productions. Their signal characteristics can be closer to environmental sounds than to sounds produced by classical musical instruments. This indicates that abstract sounds can be considered as musical as well as environmental sounds.

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